SCHOOL OF
CIVIL ENGINEERING

INDIANA
DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-87/8

Interim Report

INVESTIGATIONS ON LATEX-MODIFIED BRIDGE DECK OVERLAY CONCRETE

Sidney Diamond

PURDUE UNIVERSITY

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To: H. L. Michael, Director
Joint Highway Research Project

From: Sidney Diamond, Research Associate
Joint Highway Research Project

October 21, 1987

Project: C-36-19H

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Attached is an Interim Report of the HPR Phase II Study titled Investigations on Latex Modified Bridge Deck Overlay Concrete". The Report is entitled "A Preliminary Report on the Influence of Fly Ash Incorporation on the Properties of Latex Modified Portland Cement Concrete," and has been authored by the Principal Investigator, Professor Sidney Diamond.

The work described consists of the results of tests of compressive and flexural strength, of chloride permeability, and of certain other properties of Dow A styrene-butadiene latex modified concretes batched with 15% and 25% substitution of four representative Indiana fly ashes. It was found that incorporation of the fly ashes do not appear to appreciably degrade the excellent compressive and tensile strengths developed in latex modified concretes, and actually improve the already excellent impermeability to chloride ions.

This Interim Report is forwarded for review and acceptance by all sponsors as partly fulfilling the objectives of the Study. It will be followed in due course by the required Final Report when the study has been completed.

Respectfully submitted

Sidney Diamond
Research Associate

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16. Abstract

This interim report provides current results on a continuing project design to examine the effects of fly ash incorporation in latex-modified concrete designed for bridge deck overlays. Concretes batched with commercial styrene-butadiene latex and incorporating 15% and 25% of fly ash were prepared and the results of compr ssive strength, flexural strength, and chloride permeability testing over a six-month period are reported. Four different Indiana fly ashes, including one Class C and three Class F ashes of varying properties were used. It was found that the fly ashes did not seriously degrade the development of strength in the latex-modified concretes, and actually improved the chloride permeability test results significantly. Some variation was found between the effects of the different fly ashes, the particular Class C ash used showing generally superior effectiveness, but the differences did not appear to be of great practical importance. The differences between the results for 15% and 25% fly ash treatment levels for a given fly ash were not very great. Research is continuing on several other aspects of the behavior of latex-modified concretes incorporating fly ash.

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A Preliminary Report On The Influence of Fly Ash Incorporation on The Properties of Latex Modified Portland Cement Concrete

by

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Project No.: C-36-19H
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for

Indiana Department of Highways

and

Federal Highway Administration
U. S. Department of Transportation

Purdue University
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Oct. 21, 1987

INTRODUCTION

This report is designed to provide early and preliminary results to the Indiana State Department of Highways of our findings with respect to the influence of incorporation of selected Indiana fly ashes on certain properties of latex-modified portland cement concrete designed for overlays on bridge decks.

Their results were obtained as part of an IDOH-FHWA sponsored project entitled "Investigations on Latex Modified Bridge Deck Overlay Concrete," Indiana HPR-2005-(024). The project was initiated in the fall of 1986. At the time of its authorization the need for early information on the subject was considered critical, and it was requested that a preliminary report on the results of the investigation be provided by the end of the first year of research. This report is in response to that requirement.

It should be emphasized that the information presented is preliminary in character, and has not yet been screened, reviewed, and evaluated in the detail that is customary in scientific reporting. All findings must thus be considered provisional and all conclusions tentative.

BACKGROUND

One major impetus for the research was the indication by FHWA that latex modified concrete would not be exempt from the EPA RCRA requirement that highway department specifications could not exclude the use of fly ash in such concretes. There has been essentially no engineering evaluation or controlled research on the effects of fly ashes in such mixes, and an early indication of any potential deleterious effects was imperative.

In addition to the FHWA study authorized, IDOH initiated a smaller laboratory investigation by the Special Studies Section of the Division of Materials and Tests. The results of this evaluation were reported informally in a report by R. K. Smutzer and A. R. Zander dated March 1987. They used a single relatively poor Class F fly ash (to try to get the "worst case" established), and a mix design in which 15% of the normal complement of portland cement was replaced by approximately 19% of the fly ash (replacement ratio 1.25 to 1). They cited results for test concretes cured for ages up to 90 days.

Briefly, they found that (a) there was some pozzolanic action in the presence of the latex, (b) that both compressive and flexural strengths were slightly lower or equal to those of normal latex-modified concretes, and (c) chloride ion penetration test results were equal to or better (less permeable than) those of the normal latex-modified concrete.

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EXPERIMENTAL DESIGN

In the present research program, which is somewhat larger in scope than the study carried out by Smutzer and Zander, we used four different commercially available fly ashes selected to represent a range of properties. These included one Class C and three Class F fly ashes. Replacement levels of 15% (chosen to be "realistic"), and 25% (chosen to accentuate the effects of the fly ash, if any) were employed. These numbers represent the weight percentage of fly ash used; the weight percentages of cement withheld from the mixes were only 80% of these values, i.e. 12% and 20%, respectively.

The cement used was a Lone Star Industries Type I cement produced in Greencastle, Indiana, and widely used in the Northwestern part of the state. The latex admixture was the current Dow Modifier A styrene-butadiene formulation obtained for us from Modified Concrete Suppliers, Indianapolis through the courtesy of Mr. Smutzer. The concrete mix design incorporated approximately 30 percent of the latex admixture by weight of cement, as is customary practice in the design of such concretes, and a cement factor of 657 lbs./cu. yd.

The fly ashes used in this investigation are all well characterized materials. The Class C fly ash used, from the Rockport station of the Indiana and Michigan Electric Co. is an excellent material, and in our experience one of the best available in Indiana. The three Class F fly ashes used had varying characteristics. The Schahfer fly ash (from the Schahfer Station of Northern Indiana Public Service Company) is an extremely fine fly ash and is thought to be unusually reactive because of this. The Stout fly ash (from the Stout Station of the Indianapolis Power and Light Co.) is a typical fair quality Class F fly ash representative on many in the State. The Gibson fly ash (from the Gibson Station of Public Service Indiana, Inc. is a relatively coarse fly ash with a high content of magnetic particles, which are thought to be generally non-reactive in concrete. Such high iron content fly ashes are unusual in most parts of the world but fairly common among Indiana fly ashes.

EXPERIMENTAL RESULTS

1. <u>Properties of Fresh Concrete</u>

A. Slump

In developing mix designs for this project, the usual criterion of 4 to 6 inch slump was invoked to regulate the water content. It was found that the latex admixture used had a considerably greater water reducing action than expected, We expected to require water:cement ratios of the order of 0.4, such as had been reported for similar concretes in the classic FHWA report on latex modified concretes ["Styrene-Butadiene Latex Modifiers For Bridge Deck Overlay Concrete," by K. C. Clear and B. H. Challar, Report No. FHWA-RD-78-35, 1978]. However we found that with our latex

admixture mixes batched at water:cement ratios of 0.40 showed complete collapse slump. We had to cut back on the water content to bring the slump back to the desired range, and the final mix design for the basic latex-modified concrete (without fly ash) used a water:cement ratio of 0.29. The incorporation of the fly ashes into the mix reduced the water demand still further, and we wound up with water:(cement + fly ash) ratios ranging between 0.26 and 0.28 for the different fly ash - bearing latex modified concretes. A somewhat similar experience was reported by Smutzer and Zander.

In carrying out trial mix measurements, slump was measured immediately after mixing and again 5 minutes later. There was essentially no difference in the measurements.

No air entraining admixture was used. The apparent air contents as measured by the air pressure meter varied between 5% and 7%, before corrections for aggregate void space. However, the actual air content was later found to be significantly less than this, the aggregate void space correction being significant for the limestone aggregate used.

In all cases except for freezing and thawing tests, the concretes were cured in the mold for one day and then continuously air cured prior to testing.

2. Properties of Hardened Concrete

A. Compressive Strength

Compressive strength measurements were made as a function of time for all mixes. Data are here reported for mixes cured up to 180 days; testing at later ages will be carried out subsequently. In accordance with the usual practice with latex-modified concretes, the cylinders were cured in the molds for 1 day, then cured in laboratory air. This is apparently necessary to insure that the latex emulsion breaks properly and forms the necessary films within the matrix of the hydrating cement. There is evidence that moist curing is not required for latex-modified concrete, and indeed may be detrimental. The reference plain concretes batched for comparative purposes were continuously moist cured, as is the normal practice for plain concretes.

Fig. 1 shows compressive strength vs. time relationships for (1) a reference plain portland cement concrete using the same cement and aggregates as the latex-modified concretes (note that the plain concrete required a water:cement ratio of 0.48 to get the necessary slump); (2) the reference latex-modified concrete batched without fly ash, and (3) four different fly ash - bearing latex-modified concretes, made from the four different fly ashes and batched at the 15% replacement level.

It is apparent that use of the latex admixture substantially increases compressive strength at all ages as compared to the plain reference concrete without latex. How much of this increase is due to the lower water:cement ratio that the latex makes possible, and how much to the presence of the latex itself, is not known.

In examining the effects of incorporating the fly ashes, it is apparent

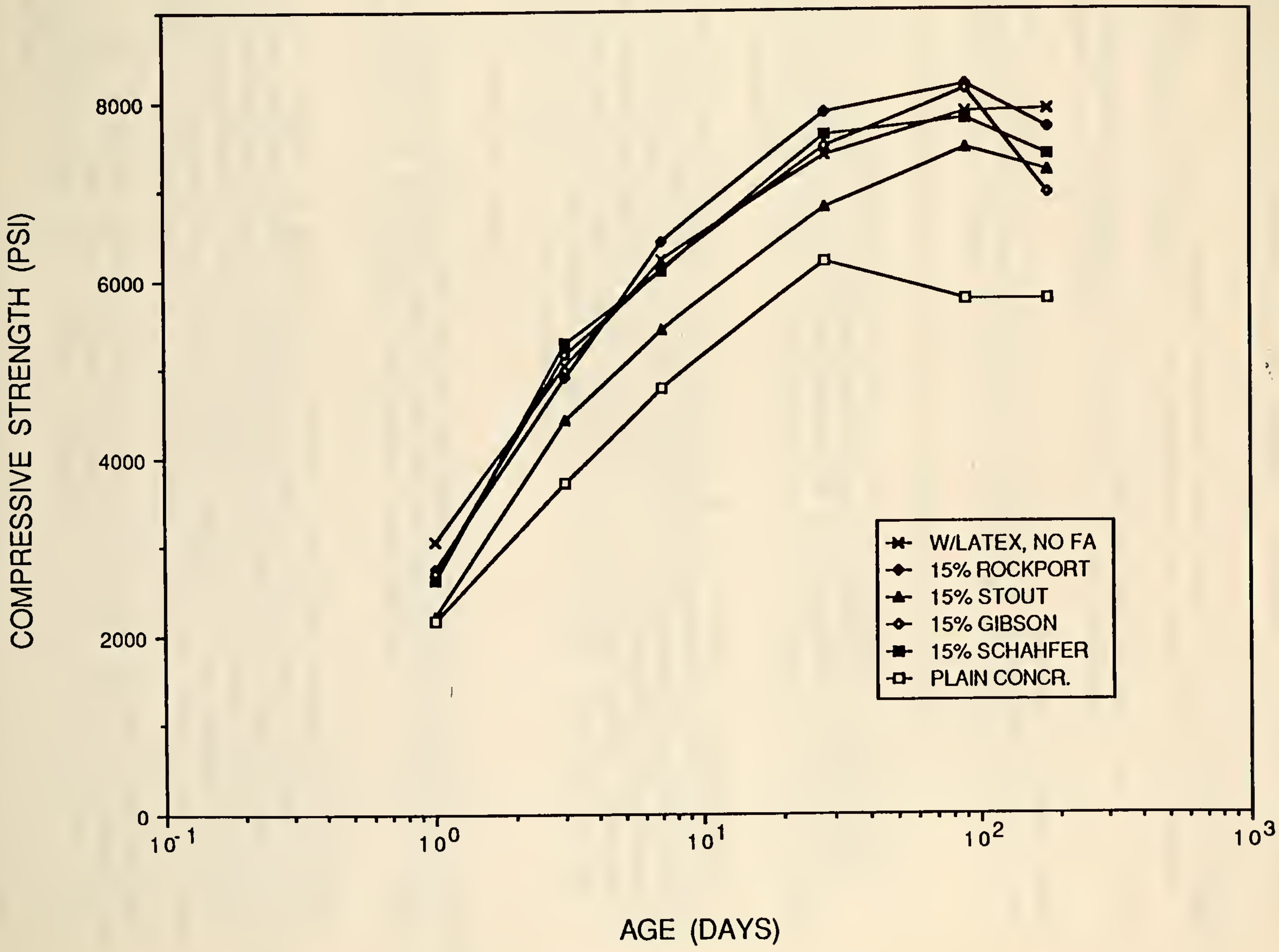

Fig. 1. Compressive strength vs. time for plain concrete, latex concrete with no fly ash, and latex concretes with 15% fly ash substitution.

that the Stout fly ash at 15% somewhat degrades the compressive strength performance of the latex-modified concrete, reducing it about 600 to 800 psi consistently at all ages. Use of all of the other fly ashes at 15% produces little or no compressive strength reduction after the first day, and indeed, the Rockport fly ash slightly increases compressive strength at later ages.

Figs. 2 through 5 show individual comparisons of compressive strength 25% replacement compared to 15% replacement for each of the fly ashes.

In general, increasing the level of fly ash replacement from 15% to 25% produces very little change in the strength gain pattern.

For the Stout fly ash (Fig. 2), 25% fly ash produces a slightly lower strength at 1 day; except for what is probably a statistical fluke in the results at 7 days, there is almost no subsequent difference.

Similar results are found for the Rockport fly ash (Fig. 3).

With the Schahfer fly ash (Fig. 4) and the Gibson fly ash (Fig. 5) there are slight but consistent reductions in strength at a given age associated with the use of 25% instead of 15% replacement. However, they effect is so small (a few hundred psi) that there would be no practical consequences.

An unexpected feature noted in all of the results is what appears to be a drop in compressive strength recorded between 90 and 180 days for all of the fly ash latex concretes. We do not at present know the cause of this unexpected behavior, and it may be of some practical consequence if it turns out to be confirmed or extended in later age testing. Results for 1 year of aging will become available in a few months, and we will pay special attention to this phenomenon.

B. Flexural Strength

Flexural strength results for reference concretes and fly ash - bearing latex concretes with fly ash at the 15% level are shown in Fig. 6 in the same way as corresponding compressive strength data were shown in Fig. 1.

Here again the general improvement that latex incorporation provides to plain portland cement concrete is obvious. The plain portland cement concrete without latex showed a flexural strength of about 500 psi at 1 day increasing linearly (with the logarithm of time) to about 1100 psi at 180 days. In contrast, the 1-day flexural strengths of the reference latex-modified concrete was about 700 psi, rising to about 1750 psi by 180 days.

Fig. 6 shows that incorporation of 15% fly ash reduced the flexural strength at 1 day from 700 psi to between 500 and 600 psi, depending on the individual fly ash. Similar reductions were observed at 3 and 7 day testing.

However, by 14 days the flexural strength of the Rockport fly ash concrete had overtaken that of the reference latex-modified concrete, and the reductions shown by the other fly ash - bearing concretes were less

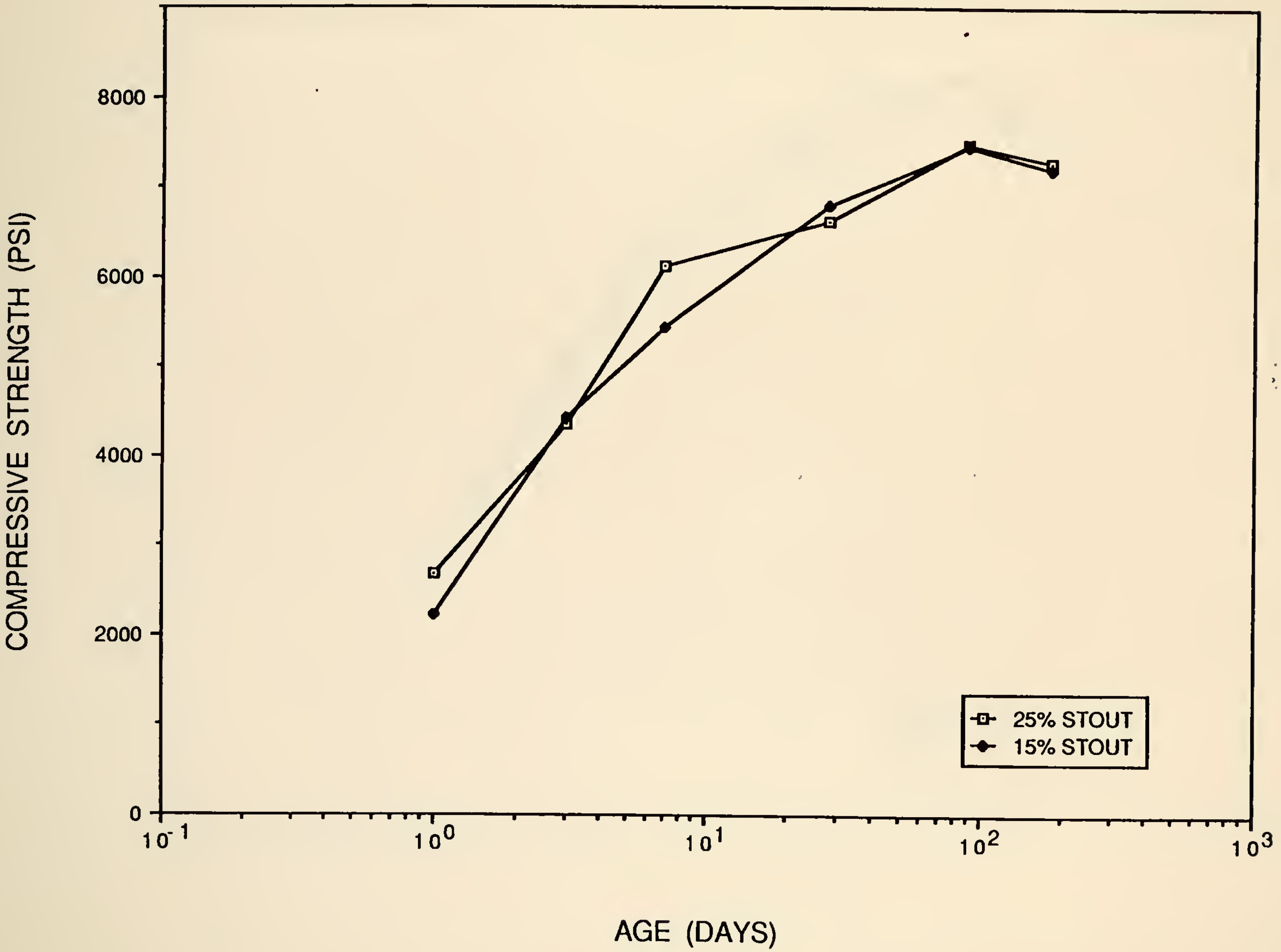

Fig. 2. Comparison of compressive strength - time responses for latex concretes with 25% vs. 15% substitutions of Stout fly ash.

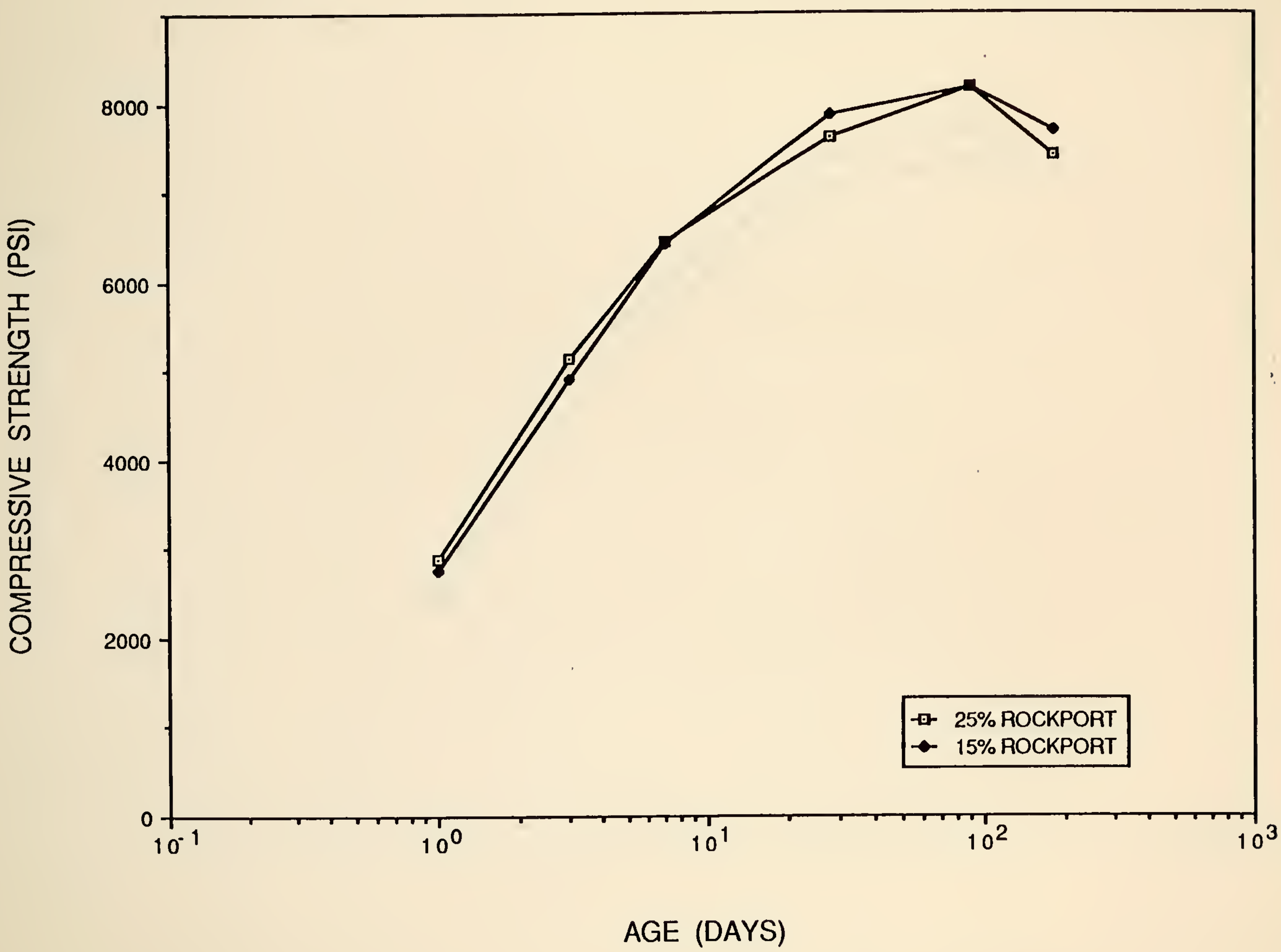

Fig. 3. Comparison of compressive strength - time responses for latex concretes with 25% vs. 15% substitutions of Rockport fly ash.

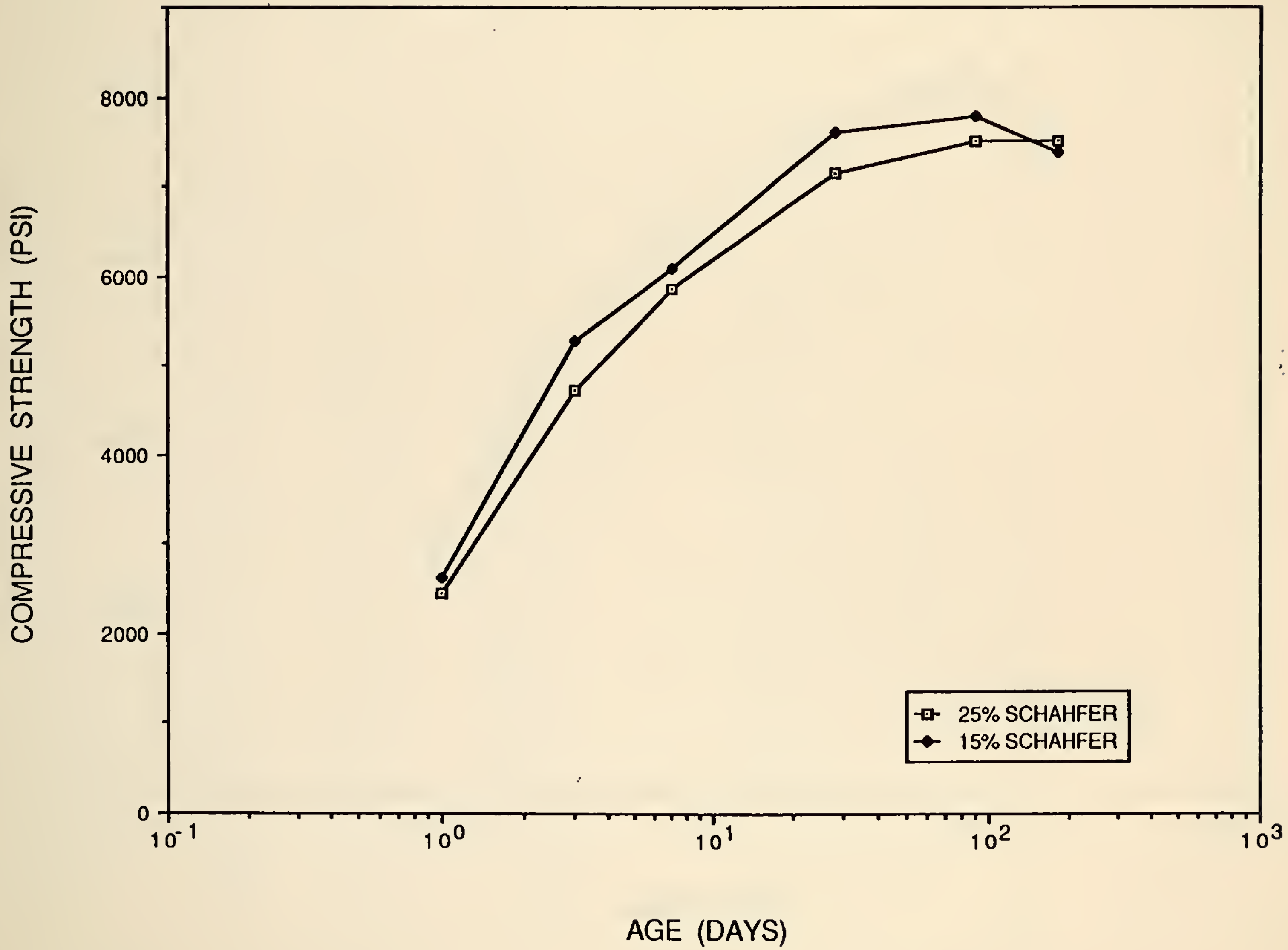

Fig. 4. Comparison of compressive strength - time responses for latex concretes with 25% vs. 15% substitutions of Schahfer fly ash.

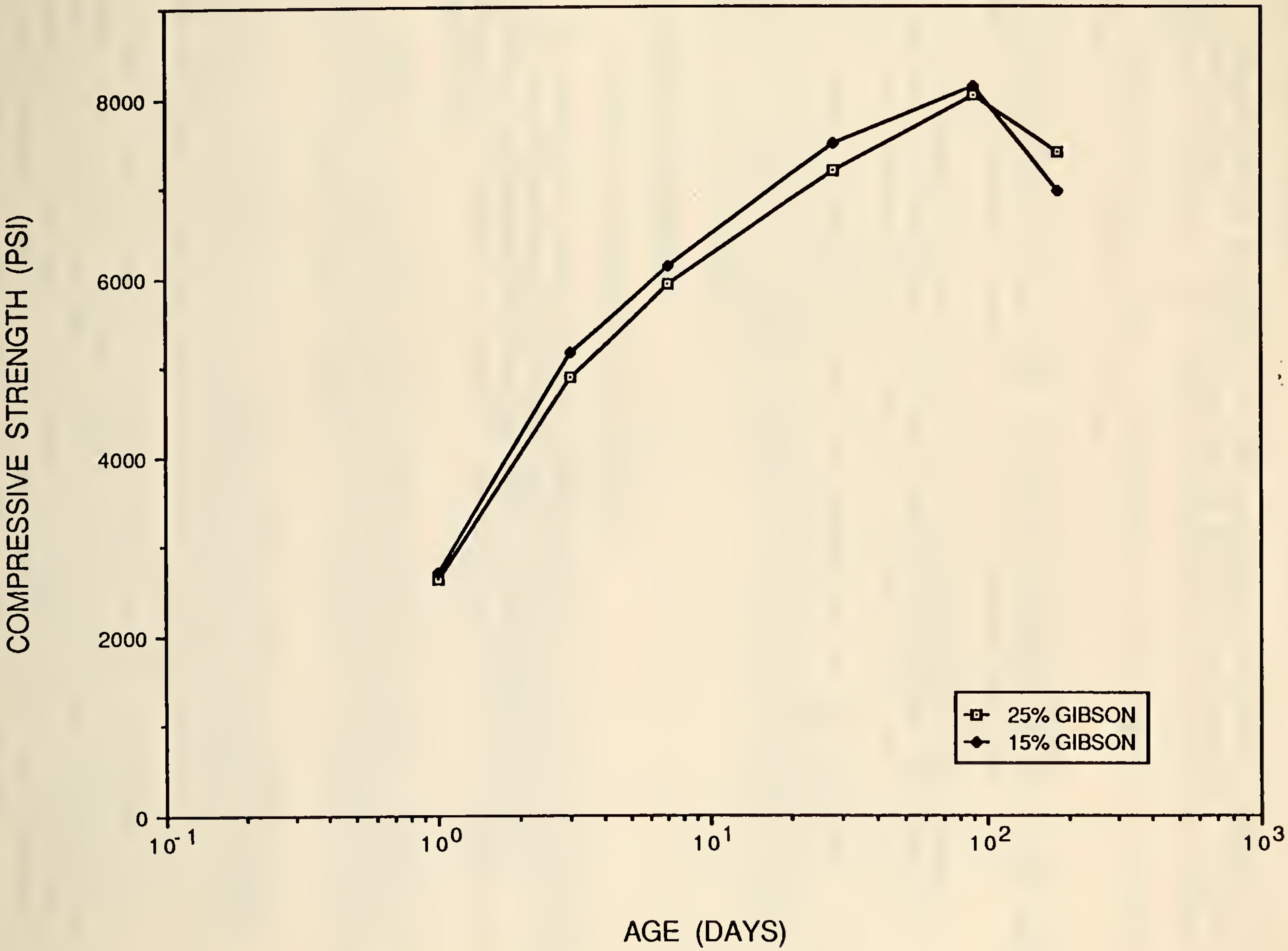

Fig. 5. Comparison of compressive strength - time responses for latex concretes with 25% vs. 15% substitutions of Gibson fly ash.

significant. By this time all of the latex - modified concretes showed flexural strengths of the order of increased to the order of 1400 psi, which is quite satisfactory. By 180 days all of these concretes showed values between about 1700 and about 1850 psi, which are highly satisfactory flexural strengths.

Comparisons of the effects at 25% replacement with these effects are provided in Figs. 7 - 10 for each of the fly ashes individually. As with compressive strength, the effects of increasing the fly level are modest.

With Stout fly ash (Fig. 7), the there is a small reduction in flexural strength, but primarily at later ages.

With Rockport fly ash (Fig. 8) there is a small increase at early ages, suggesting that this Class C fly ash may be chemically active in the early hydration processes. However, the effect becomes negligible later.

With Schahfer fly ash (Fig. 9) there is a slight flexural strength enhancement at later ages, and with Gibson fly ash (Fig. 10) there is a slight but consistent flexural strength reduction all the way through.

In terms of practical effects, the differences are not important. It must be concluded that use of the fly ashes at the 25% replacement level does not degrade the excellent flexural strength results obtained at the 15% level; indeed, depending on the fly ash, flexural performance may even be enhanced slightly.

3. Durability Parameters

A. Chloride Permeability Measurements

We were much concerned with possible effects of fly ash incorporation on the rate of movement of chloride ions through the system, since one of the major justifications for the high cost of latex-modified concrete overlays is the corrosion protection they provide for the underlying steel reinforcement.

Smutzer and Zander used the standard calcium chloride ponding test and found that the effect of using a 15% replacement of their single fly ash was that the resulting concrete was "less pervious or essentially equal to the normal latex-modified concrete".

In our investigations we used the FHWA chloride permeability test (AASHTO T 77-831) on latex-modified concretes that had been air cured for approximately 80 days, and on a reference portland cement concrete that had been continuously moist cured for the same period.

Two-in. thick slices were obtained from specially cast cylinders of either 6-in. or 12-in. original height. Previous chloride permeability testing of concrete from cast cylinders had indicated some effect of the location of the slice taken with respect to vertical axis of the cylinder. All of our specimens were 2 in. slices taken from the top of each cylinder, after sawing off a 5-mm layer of the very top surface material.

As will be seen in the result, specimens taken from the top of a

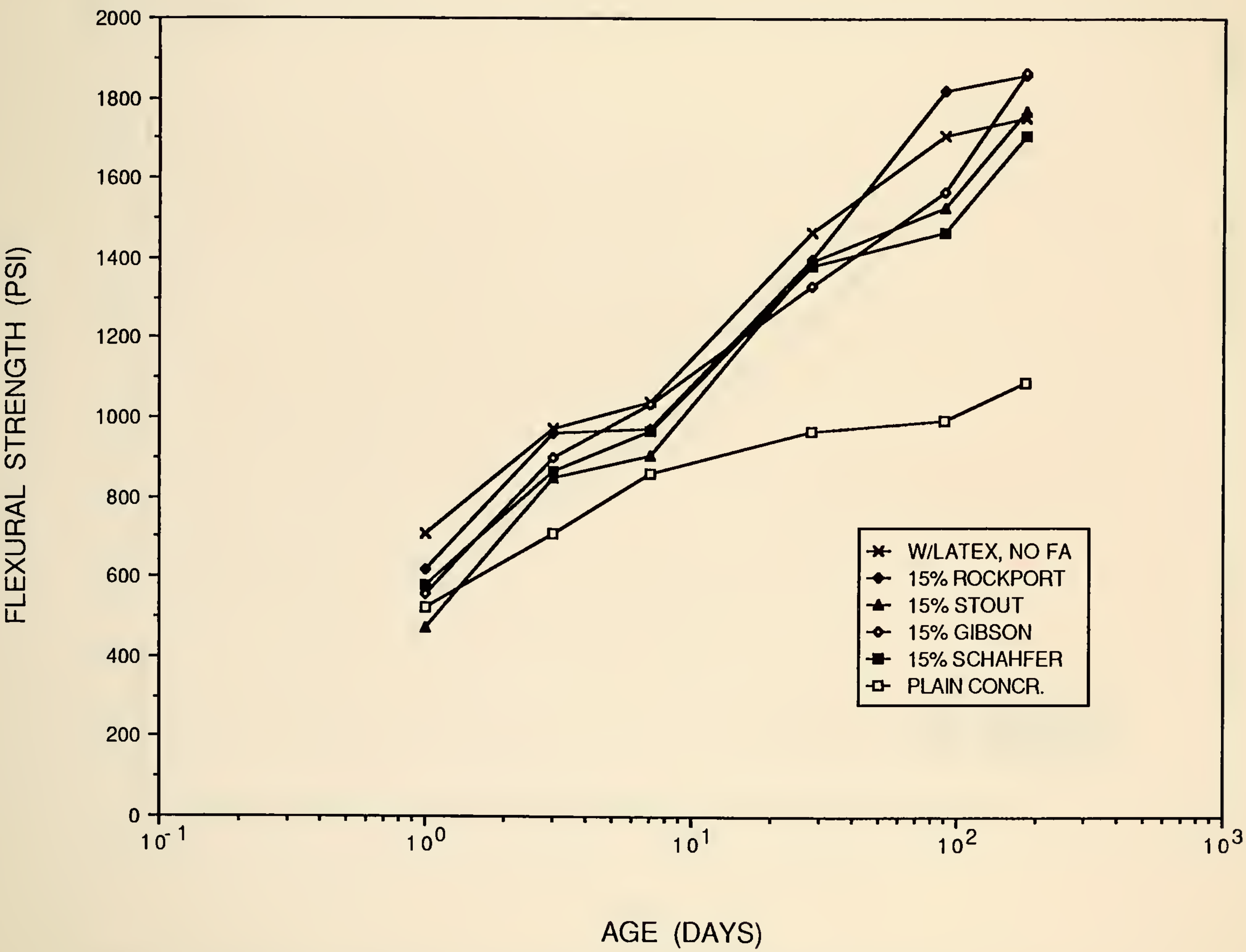

Fig. 6. Flexural strength vs. time for plain concrete, latex concrete with no fly ash, and latex concretes with 15% fly ash substitution.

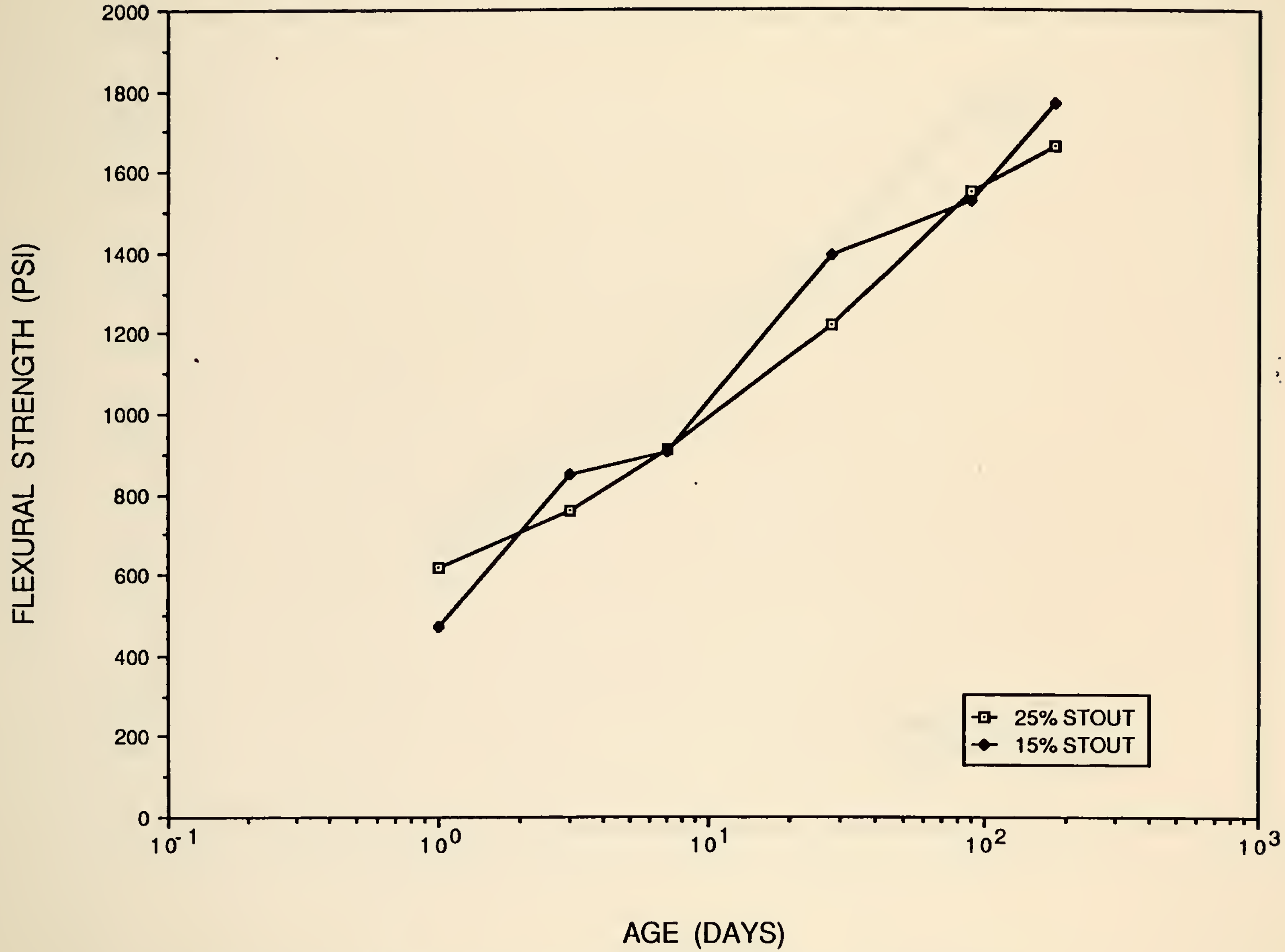

Fig. 7. Comparison of flexural strength - time responses for latex concretes with 25% vs. 15% substitutions of Stout fly ash.

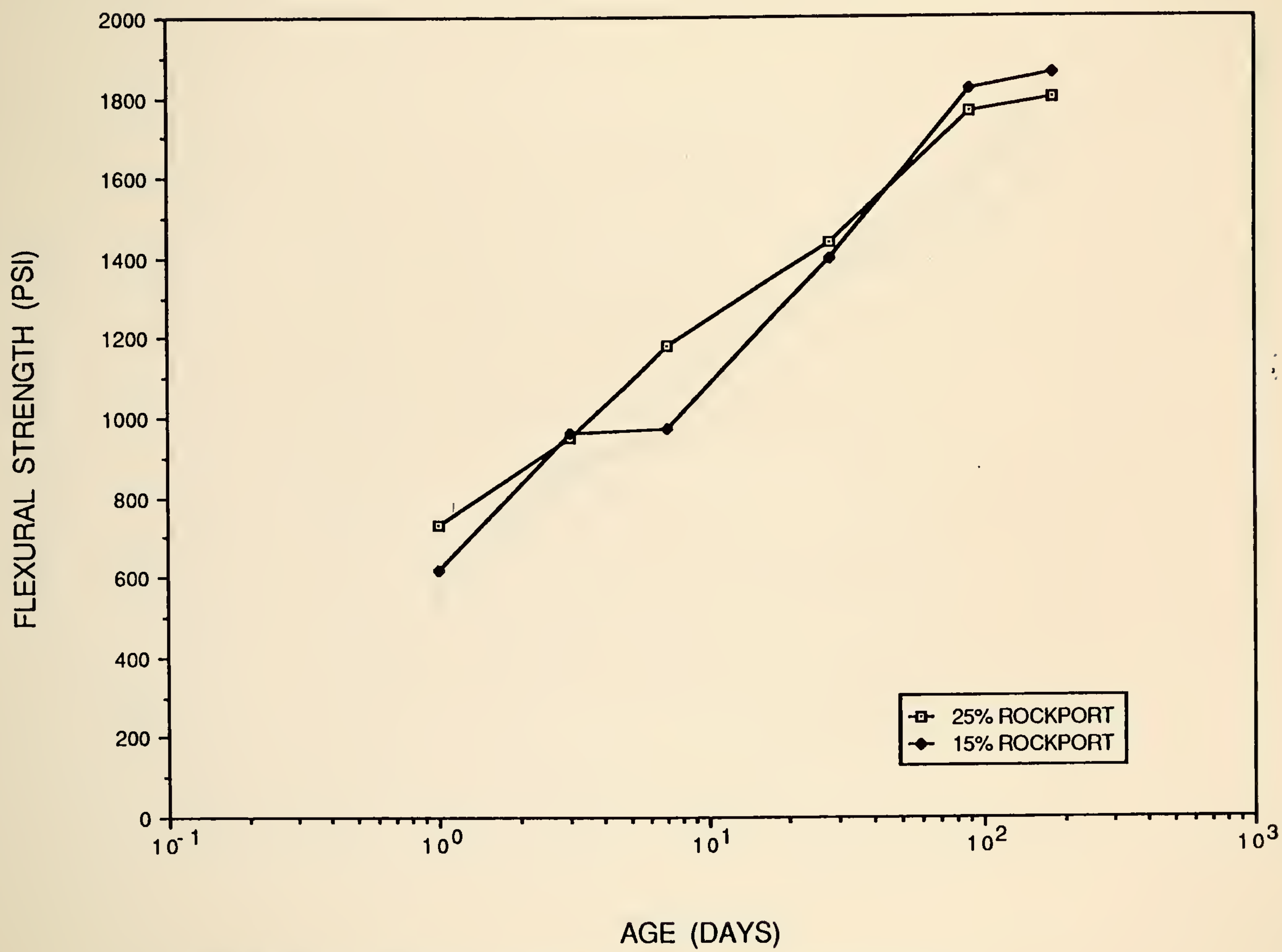

Fig. 8. Comparison of flexural strength - time responses for latex concretes with 25% vs. 15% substitutions of Rockport fly ash.

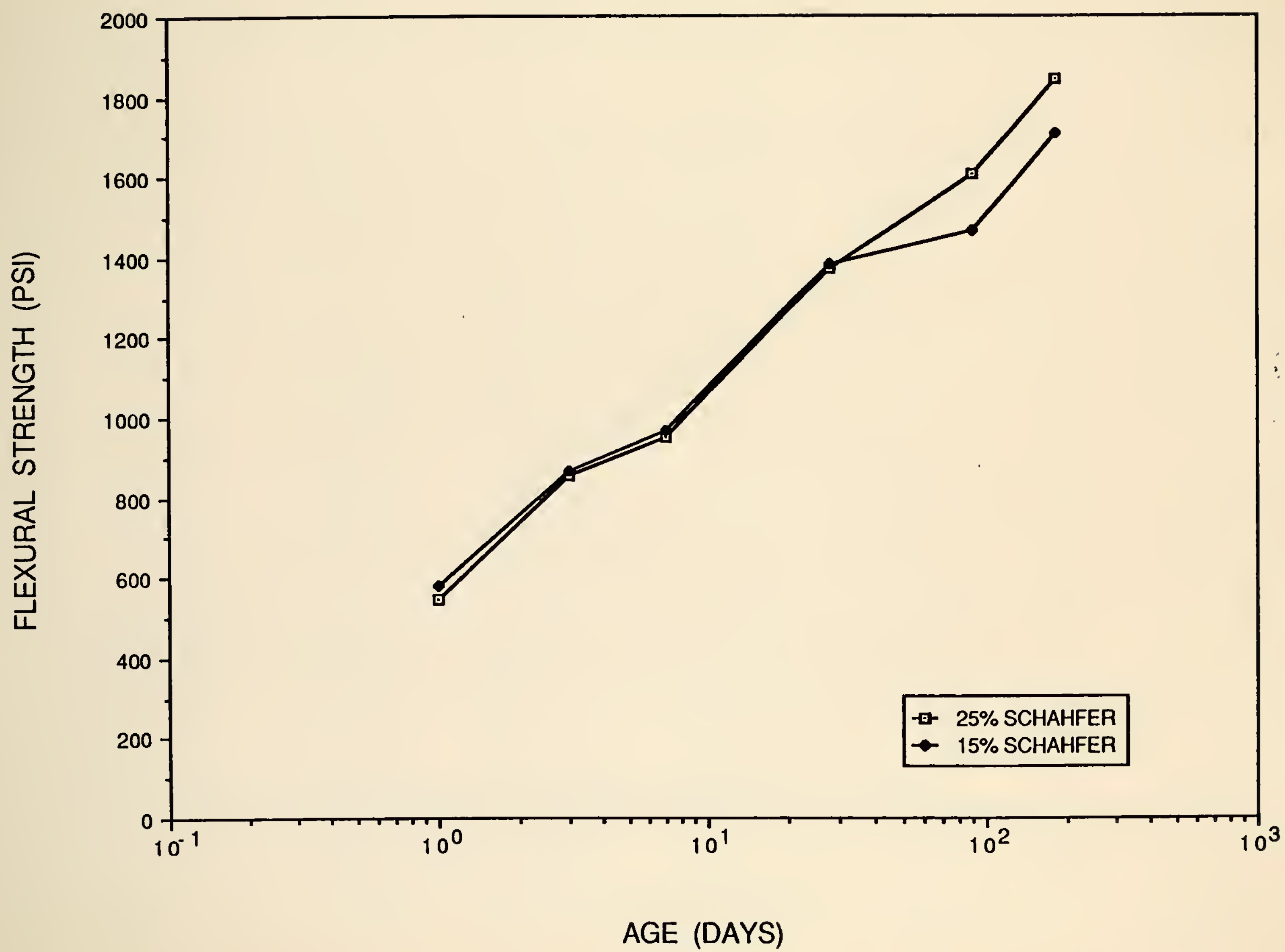

Fig. 9. Comparison of flexural strength - time responses for latex concretes with 25% vs. 15% substitutions of Schahfer fly ash.

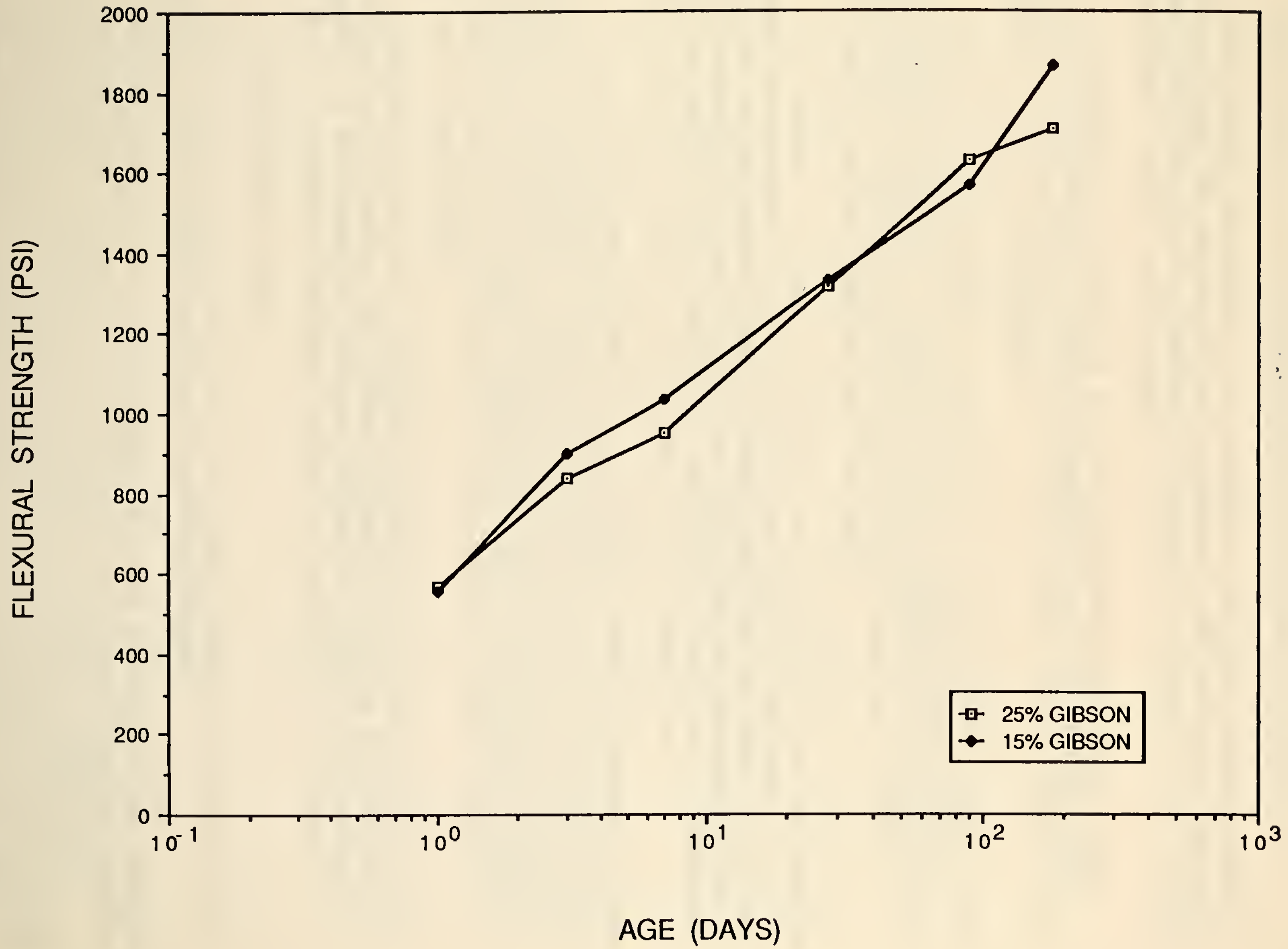

Fig. 10. Comparison of flexural strength - time responses for latex concretes with 25% vs. 15% substitutions of Gibson fly ash.

6 - in. cylinder were consistently a little bit less permeable than corresponding specimens sliced from a 12 -in. cylinder, but the magnitude of the effect was small.

The results of the testing program are provided in Table 1.

The average permeability (in coulombs) of the plain portland cement concrete made with the cement and aggregates used throughout was about 3,000. This falls into the "moderate permeability" category of the AASHTO classification (2000 - 4000 coulombs).

As expected, the reference latex-modified portland cement concrete showed a much reduced chloride permeability, the average value being about 560 coulombs. This is "very low permeability" by the standard classification (100 - 1000 coulombs).

Somewhat unexpectedly, incorporation of each of the fly ashes resulted in further reductions of the permeability as compared to the reference latex-modified concrete. There were some differences among the fly ashes, the Rockport (Class C) ash and the Gibson ash being more effective in this regard than the Schahfer and Stout ashes.

Furthermore, it appears that 25% fly ash substitution confers somewhat greater improvement than 15% fly ash substitution in this sense. Table 2 provides the data showing the percentage reduction (on average) of chloride permeability for each fly ash-bearing concrete as compared to the reference latex-modified concrete. It is apparent that there is significant additional effect in going to the higher fly ash substitution.

The practical consequence of this additional effect is probably immaterial, since the differences in measured chloride permeabilities are not likely to show up in substantial differences in field behavior, but the theoretical consequence is important. The inference we draw is that the fly ash (or something in it, most likely the glass) is actively slowing down chloride movement; hence the increased effect accompanying a greater proportion of fly ash in the concrete.

The main and obvious conclusion resulting from these results is that seems to be no practical worry about fly ash interfering with the impermeability of latex-modified concrete overlays to chloride; the presence of fly ash is apparently beneficial, rather than harmful in this respect.

B. Freeze-Thaw Results

The subject of air content, air void spacing factor, and freeze-thaw testing in latex modified concrete is somewhat tangled.

The FHWA "bible" on latex modified concrete for bridge deck overlays [FHWA-RD-78-35, referred to previously] indicates that freezing resistance of latex-modified concrete is not a problem in the field, despite poor performances of test concretes in the ASTM C 666 freeze-thaw testing. In a more recent review of the performance history of latex-modified concrete overlays Kuhlmann extensively reviewed service histories of such materials by the various state highway departments and FHWA and did not even mention freezing damage as a potential problem [L. E. Kuhlmann, "Perfor-

TABLE 1. Results of Chloride Permeability Tests on 2-In. Thick Concrete Slices

Concrete Type	Height of Original Concrete Cylinder	Relative Chloride "Permeability", Coulombs
Reference plain	6 in.	2941
portland cement	12 in.	3137
concrete	-------	----
	Average	3039
Reference latex	6 in.	576
modified concrete	12 in.	557
(without fly ash)	-------	----
	Average	566
Latex-modified	6 in.	392
concrete with	12 in.	458
15% Rockport ash	-------	----
	Average	425
Latex-modified	6 in.	353
concrete with	12 in.	338
25% Rockport ash	-------	----
	Average	345
Latex-modified	6 in.	439
concrete with	12 in.	514
15% Schahfer ash	-------	----
	Average	476
Latex-modified	6 in.	349
concrete with	12 in.	399
25% Schahfer ash	-------	----
	Average	374
Latex modified	6 in.	421
concrete with	12 in.	608
15% Stout ash	-------	----
	Average	515
Latex modified	6 in.	370
concrete with	12 in.	457
25% Stout ash	-------	----
	Average	413
Latex modified	6 in.	356
concrete with	12 in.	375
15% Gibson ash	-------	----
	Average	476
Latex modified	6 in.	280
concrete with	12 in.	380
25% Gibson ash	-------	----
	Average	330

TABLE 2. Percentage Reduction in Average Measured Chloride Permeability on Incorporating Fly Ash (As Compared to Reference Latex Modified Concrete)

Fly Ash Type	Level of Fly Ash Substituted 15% Fly Ash	25% Fly Ash
Rockport	25	39
Schahfer	16	34
Stout	9	27
Gibson	36	42

mance History of Latex-Modified Concrete Overlays," pp. 123 - 144 in "Applications of Polymer Concrete, A.C.I. Publication SP-69, 1981].

Nevertheless, we included a series of C-666 Method A freeze thaw tests in our research. In this program the test bars were made using the standard mix design, without addition of any air entraining agent.

As indicated earlier, the nominal air contents of the fresh concretes measured by the pressure meter was on the order of 6 percent. However, the necessary correction for void space in the limestone aggregate used was omitted from consideration at the time. Incorporating this correction, the actual air contents as batched were close to 4%. rather than about 6%. This is approximately what Clear and Chollar of FHWA found with their Dow A - modified concretes in the absence of added air entraining agent, as described in the FHWA report previously mentioned. Spot measurements carried out on polished specimens of our hardened concrete confirmed that this was the order of magnitude of the true air content, and further indicated that the air voids were comparatively coarse, i.e. had a high spacing factor.

Freeze-thaw testing of all of the present concretes was carried out with the assistance of the Division of Materials and Tests of IDOH. These specimens were air cured for 13 days after demolding, then cured in water for several weeks prior to testing.

There were some irregularities in the test procedure due to equipment malfunction, but it was found that all of the specimens failed the test, The fly ash - bearing latex modified concretes did no worse in this testing than did the reference latex - modified concrete, all of the materials showing relative durability factors of between 55% and 60% after 300 cycles. Results not much different from these were reported for plain latex-modified concrete (without fly ash) by Clear and Chollar in the FHWA report previously referred to.

Because of the uncertainties in the test program and equally great uncertainties in the proper interpretation of the results, we prefer not to formally report the actual freeze-thaw data at the present time. Specimens are being prepared for another series of freeze thaw tests, this time with sufficient air entraining agent added to bring the actual air content to at least 6 percent. The results of these tests, and of further efforts at understanding and interpreting the freeze thaw responses of fly ash bearing latex-modified concrete will be reported subsequently.

OTHER TESTING IN PROGRESS

Tests for the dynamic modulus of elasticity (Young's modulus) of all of the concretes have been carried out, but the results have certain inconsistencies that lead to some questioning of their validity. The matter is still under investigation and we prefer not to report these results at the present time.

Bond testing has been held up considerably because of equipment difficulties. After consultation with the Study Advisory Board members we

have decided to use the Swedish break-off tester for this purpose; however, delays have occurred and we are just now in the process of getting what we hope are reliable bond test data. These will be reported subsequently.

Scanning electron microscope examination of film formation and the visible effects of the fly ash have not yet proceeded to the stage where we are ready to report the results.

CONCLUSIONS

While it is premature to draw final conclusions on a research project still in progress, the information presented leads us to the following tentative conclusions:

1. The incorporation of as much as 25% of fly ash as a partial substitute for portland cement in latex-modified concrete does not seriously degrade the high compressive strengths developed by such concretes. The actual effect depends somewhat on the specific fly ash, and at least one superior fly ash (Rockport) was found to slightly increase compressive strengths as compared to the reference latex-modified concrete without fly ash incorporation.

2. Fly ash similarly did not significantly degrade the development of flexural strength, and the high flexural strengths required for successful bridge deck overlay service and obtained by ordinary latex-modified concretes were also obtained with as much as 25% fly ash substitution. Again, the type of fly ash was of some significance, but in practical terms the flexural strengths developed with all of the fly ashes used would be judged acceptable.

3. As a consequence of the results reported above it appears that the prior concerns that latex films might interfere with the processes of reaction of fly ash with the hydrating cement system seem to have been unjustified.

4. The inclusion of fly ash in latex-modified concrete was found to actually improve the already high degree of impermeability to chloride ions ordinarily shown by latex-modified concrete on the basis of the electrical chloride permeability test.

A number of unanswered questions have been raised by the results of the test program, including:

(a) Does the unexpectedly high water reducing ability of the latex we used (which was also found by Smutzer and Zander) stem from a change in the formulation of the admixture?

(b) Is the drop in compressive (but not flexural) strength found for all the fly ash - bearing latex modified concretes at 180 days real, and if so, will later strengths degrade further?

(c) Is the freezing resistance of latex-modified concrete properly

assessed by the standard C 666 freeze thaw test, and if so, is the same low bubble spacing factor required to insure freeze-thaw resistance as is required for ordinary concrete?

We hope to investigate these matters further in subsequent research.

ACKNOWLEDGEMENT

Most of the work reported here was carried out by Mr. Qizhong Sheng as part of his graduate research program. The able assistance and guidance provided to him by Mr. Jan Olek is very much appreciated.

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